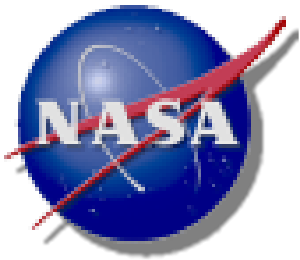


Full shell alignment and mounting

Mikhail (Misha) Gubarev

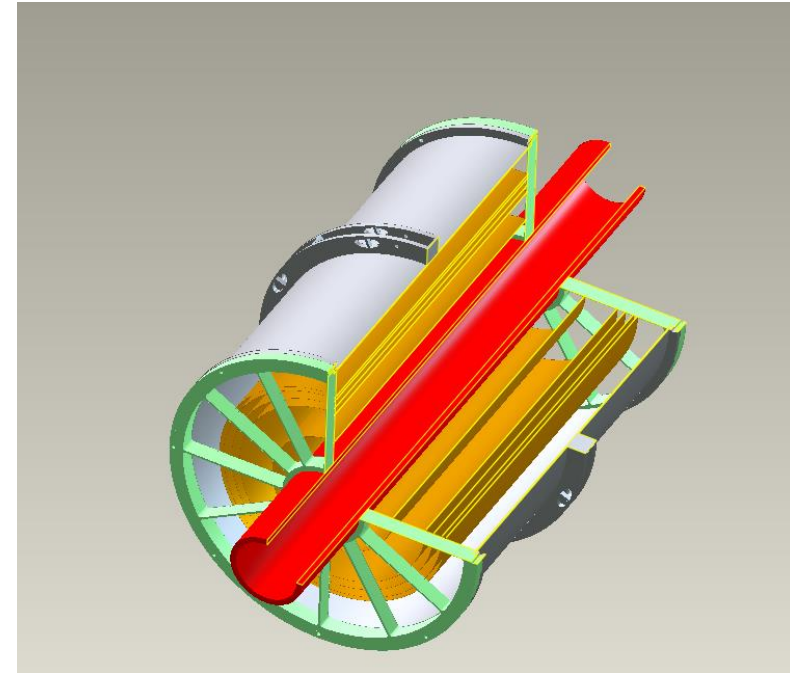


Full-Shell Mirrors

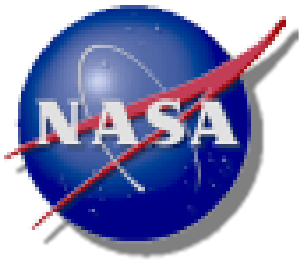
Full shell mirrors are stable and can be self-supporting.

If shells have a monolithic structure containing the alignment of the H and P segments to each other is avoided.

x-ray mirrors need to be mounted and co-aligned (hopefully) without further degradation of the angular resolution



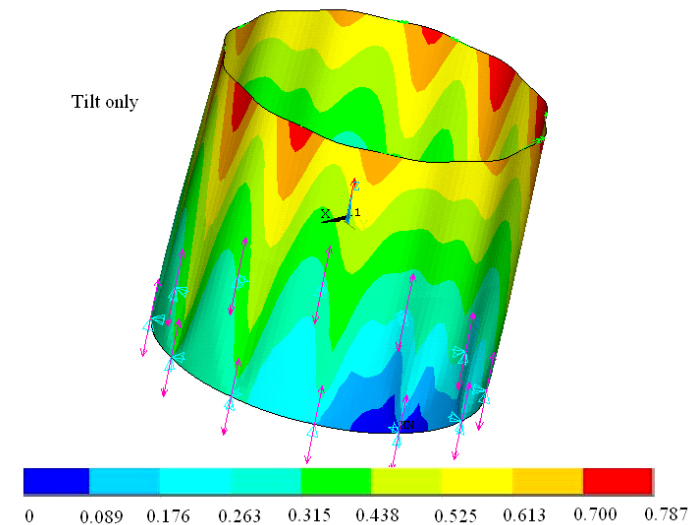
A schematic representation of the x-ray telescope module. For simplicity only five mirror shells are shown. The actual number of spider spokes to support the nested mirror shells for the flight module is still to be determined.



Any radial distortion on one edge of the shell leads to distortions on other end of the shell

Table 1. Sensitivities of the image rms diameter to various surface errors. calculated for a typical 23-cm diameter, 60-cm length, 10-meter-focal-distance mirror shell

Surface error type	Image rms diameter sensitivity
Delta-delta-radius	7.71 arc sec per μm rms
Average axial sag	17.8 arc sec per μm
Axial slope	8 arc sec per arc sec rms
Roundness	0.0922 arcsec per μm rms
Circumferential slope	0.023 arcsec per arc sec rms
De-center	0.021 arc sec per μm



Deformation maps for the 34 cm diameter, 60 cm length monolithic shell supported with 12 points at the bottom of the mirror. The shell is tilted by 1 microradian. The distortion scale is in microns.

Analytical Model



- Kirchhoff-Love Theory: Linear theory of thin elastic shells
- Assumptions
 - Kirchhoff-Love Assumptions: neglect strains normal to middle surface; displacement \ll shell thickness
 - Coplanar mounting points orthogonal to optical axis
 - Plate-like deflection with periodic boundary conditions
 - Neglect cone angles
- Steps
 - Select mounting locations and characteristics
 - Determine boundary conditions
 - Solve for deflections using variational principles for the stationary point of the static total Lagrangian
- General Solution for cylindrical shell
 - Solve for deflection, $\eta(\theta, z)$:

$$\nabla^2 \nabla^2 \eta(\theta, z) = C \delta(z - z_1) \sum_{n=0}^{\infty} k(n, 1) \cos(\theta n) + k(n, 2) \sin(\theta n)$$
 - solution for the n^{th} harmonic of θ , n initially limited to 2&3:

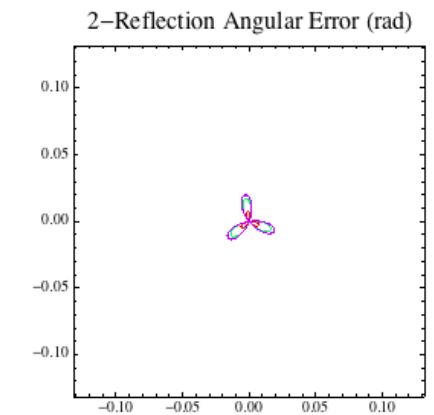
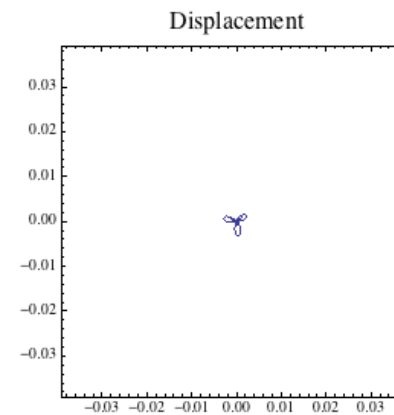
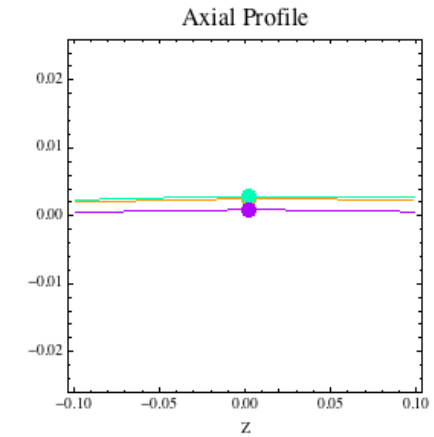
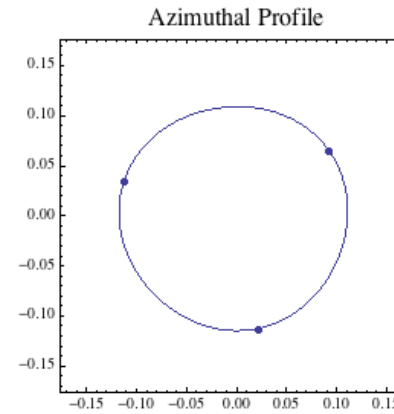
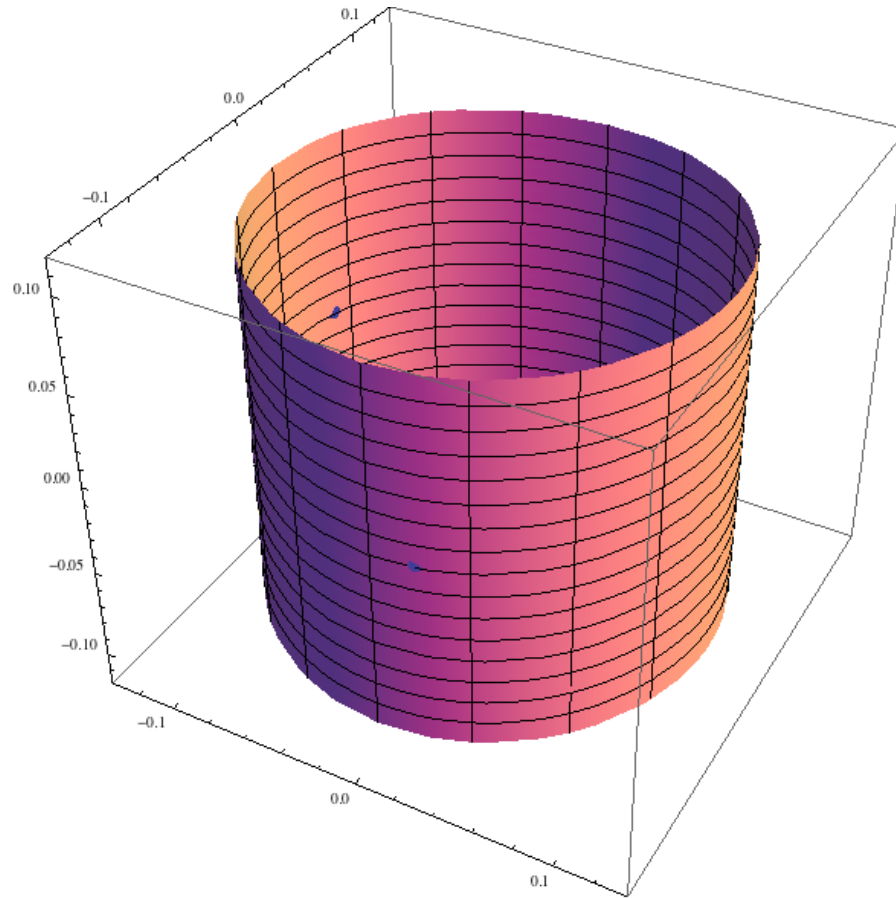
$f(n, \theta, z, R, z_1) =$

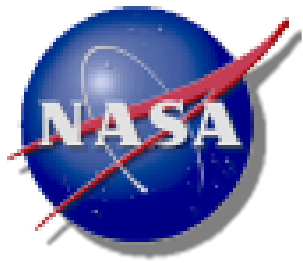
$$\begin{aligned} & \cos(\theta n) \left(\frac{a(n, 1, 5)}{2 n^3} \theta(z - z_1) \left(\frac{n(z - z_1)}{R} \cosh\left(\frac{n(z - z_1)}{R}\right) - \sinh\left(\frac{n(z - z_1)}{R}\right) \right) + a(n, 1, 3) \sinh\left(\frac{n z}{R}\right) + a(n, 1, 4) \frac{n z}{R} \sinh\left(\frac{n z}{R}\right) + a(n, 1, 1) \cosh\left(\frac{n z}{R}\right) + \right. \\ & \quad \left. a(n, 1, 2) \frac{n z}{R} \cosh\left(\frac{n z}{R}\right) \right) + \\ & \sin(\theta n) \left(\frac{a(n, 2, 5)}{2 n^3} \theta(z - z_1) \left(\frac{n(z - z_1)}{R} \cosh\left(\frac{n(z - z_1)}{R}\right) - \sinh\left(\frac{n(z - z_1)}{R}\right) \right) + a(n, 2, 3) \sinh\left(\frac{n z}{R}\right) + a(n, 2, 4) \frac{n z}{R} \sinh\left(\frac{n z}{R}\right) + a(n, 2, 1) \cosh\left(\frac{n z}{R}\right) + \right. \\ & \quad \left. \frac{n z}{R} a(n, 2, 2) \cosh\left(\frac{n z}{R}\right) \right) \end{aligned}$$



Visualization

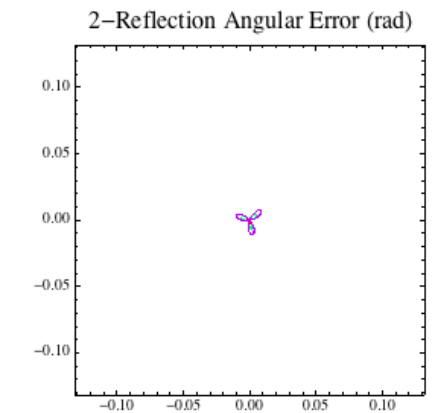
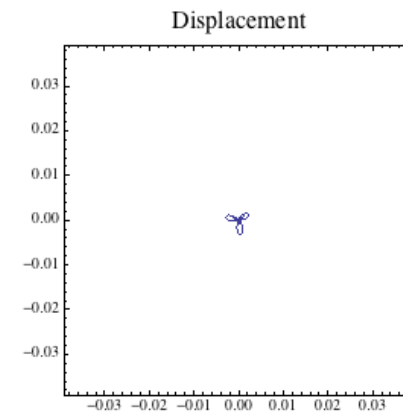
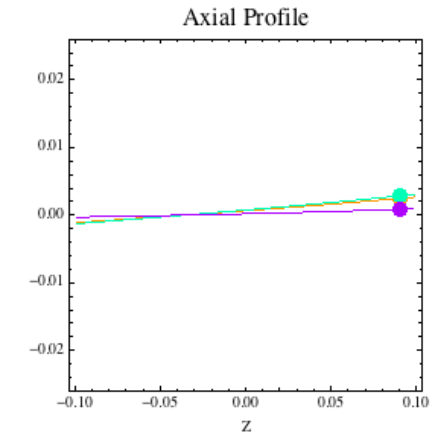
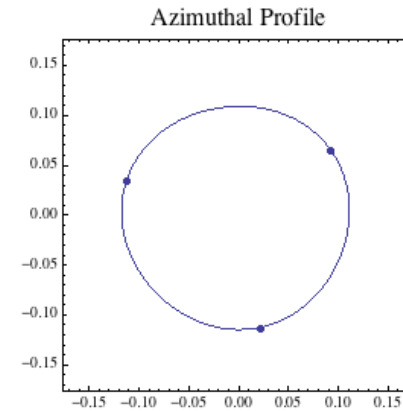
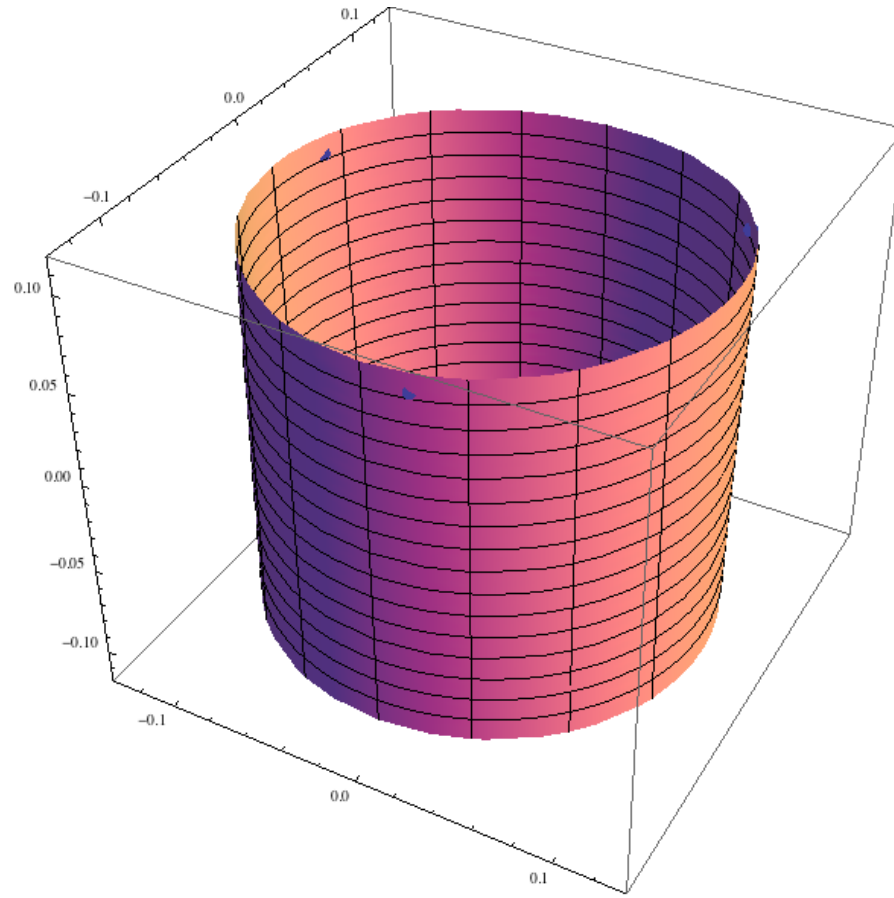
- Animation of deflection patterns for applied loads at axial center
 - deflection pattern is exaggerated

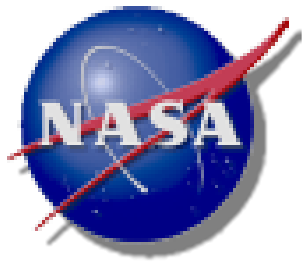




Visualization

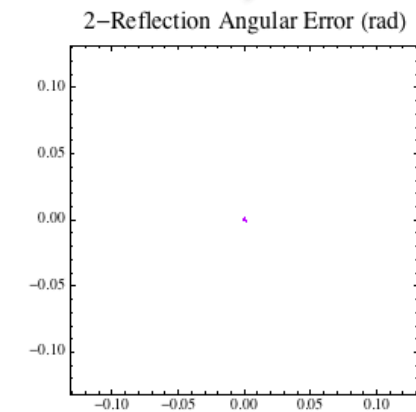
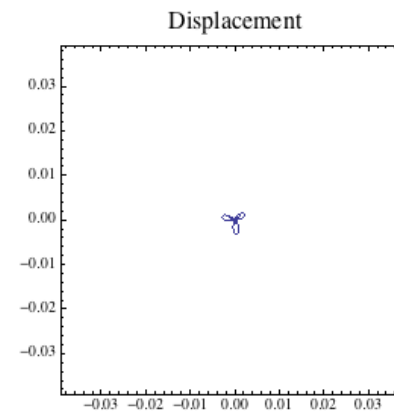
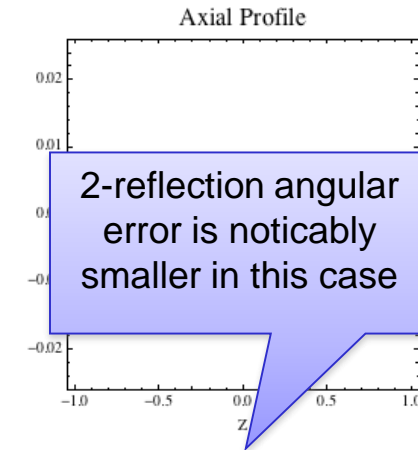
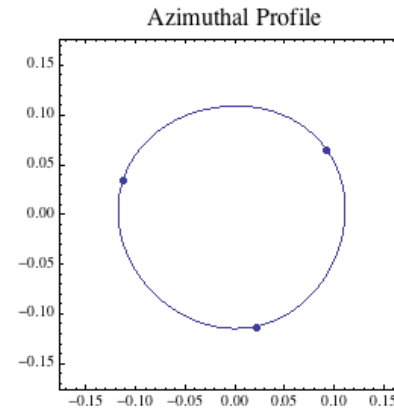
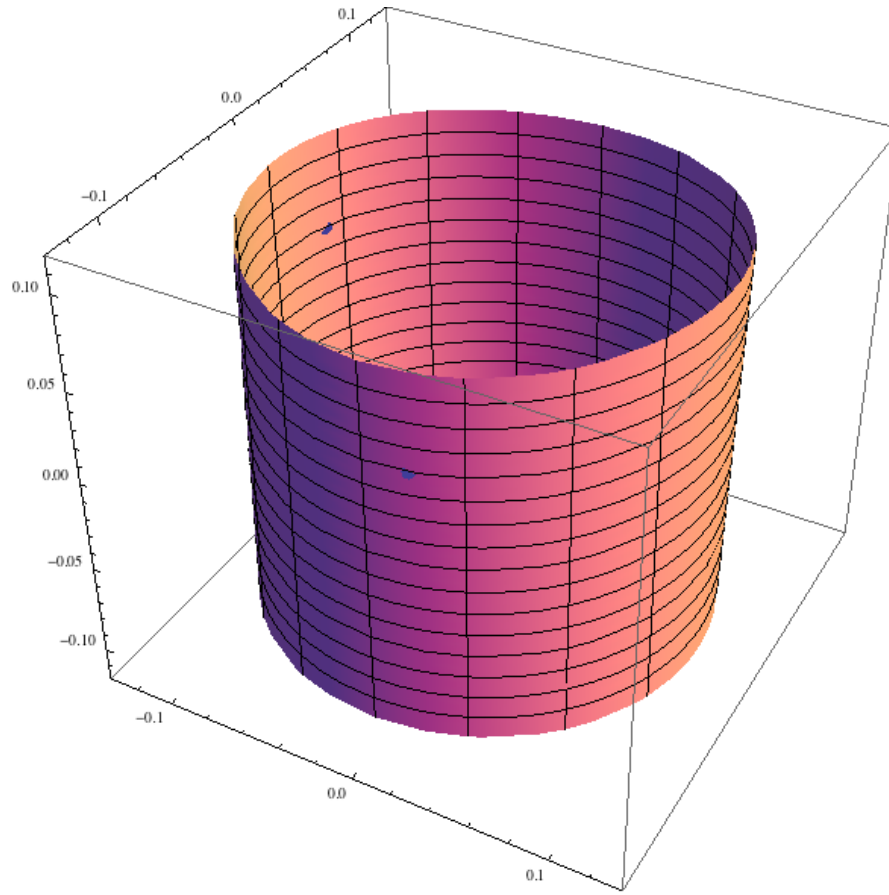
- Animation of deflection patterns for applied loads at axial edge

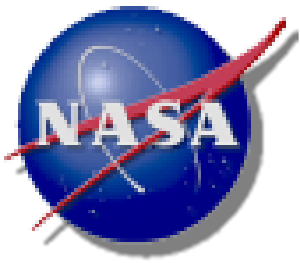




Visualization

- Animation of deflection patterns for applied loads half-way between edge and center

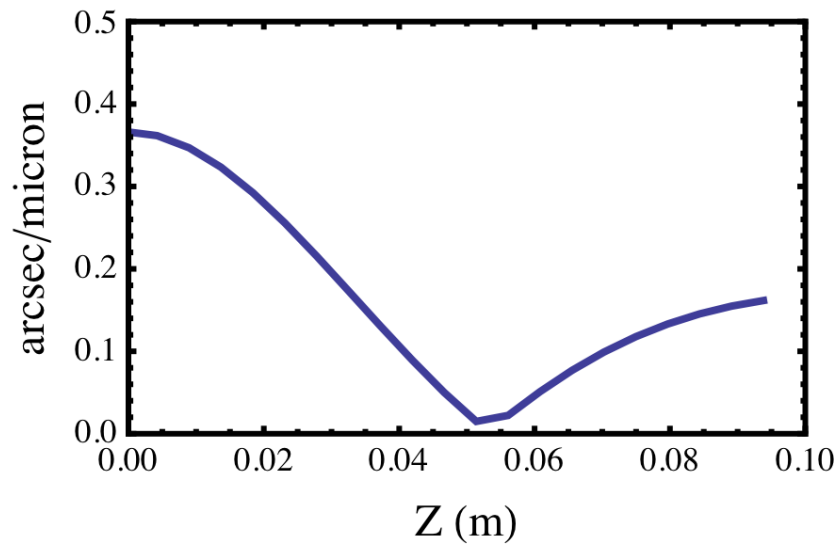




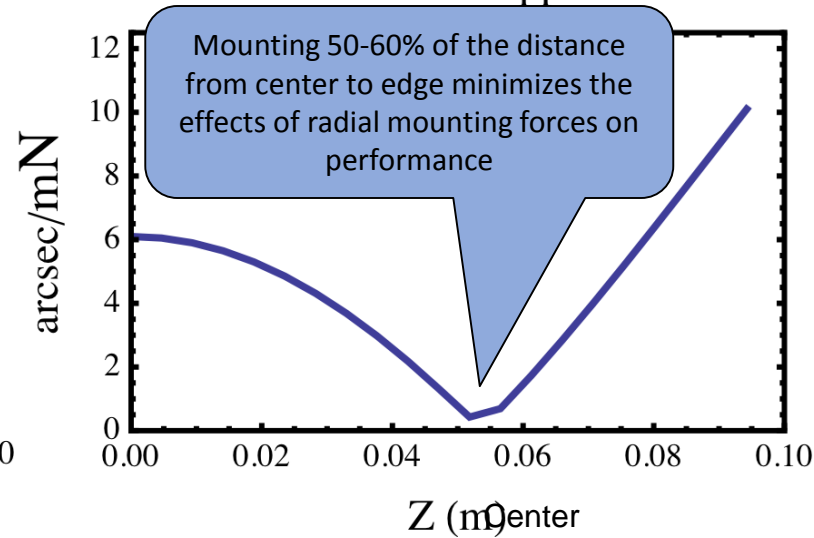
Example: Performance vs. Axial Mounting Location

- 2-reflection RMS angular deviation
 - constant deflection
 - constant force
- Inflection points are akin to Airy Points in precision metrology ($0.577 \times \text{length}$)

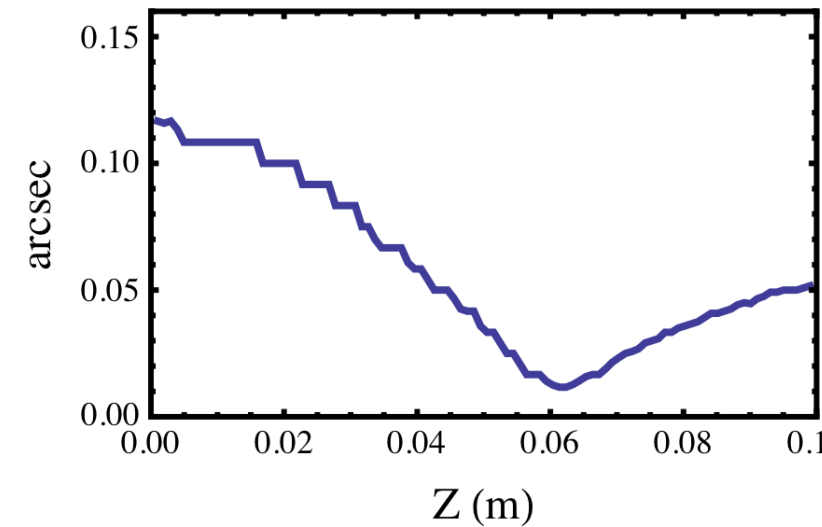
2-Reflection RMS Angular Deviation per Unit Deflection vs. Axial Position of Applied Force

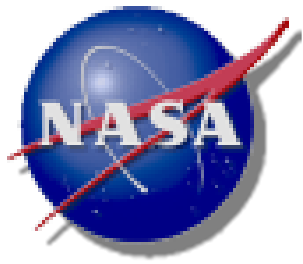


2-Reflection RMS Angular Deviation per Unit Force vs. Axial Position of Applied Force



2-Reflection HPD for 10 micron Deflection vs. Axial Position of Applied Force

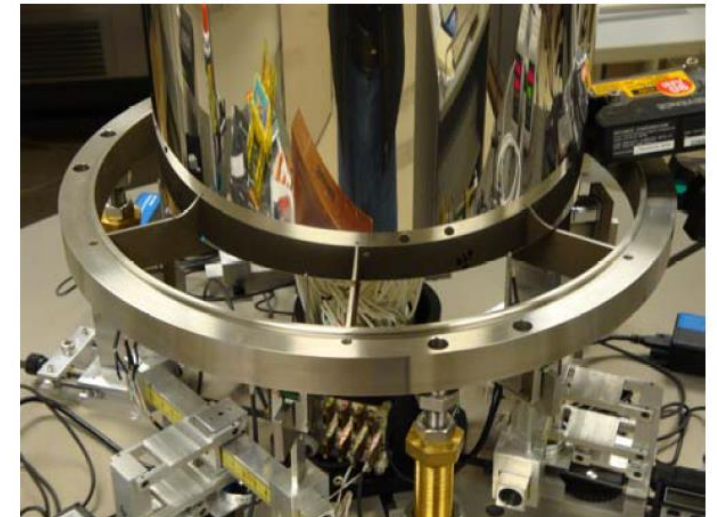
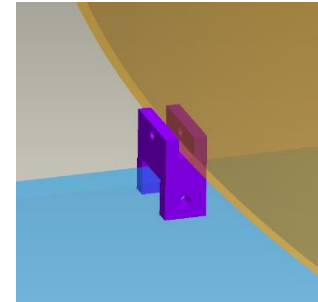


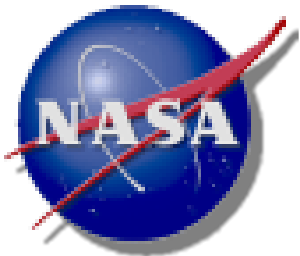


Alignment

Shell can be glued from one end

The use of the clips (FOXSI – 2007)
minimizes the distortions due to epoxy
shrinking



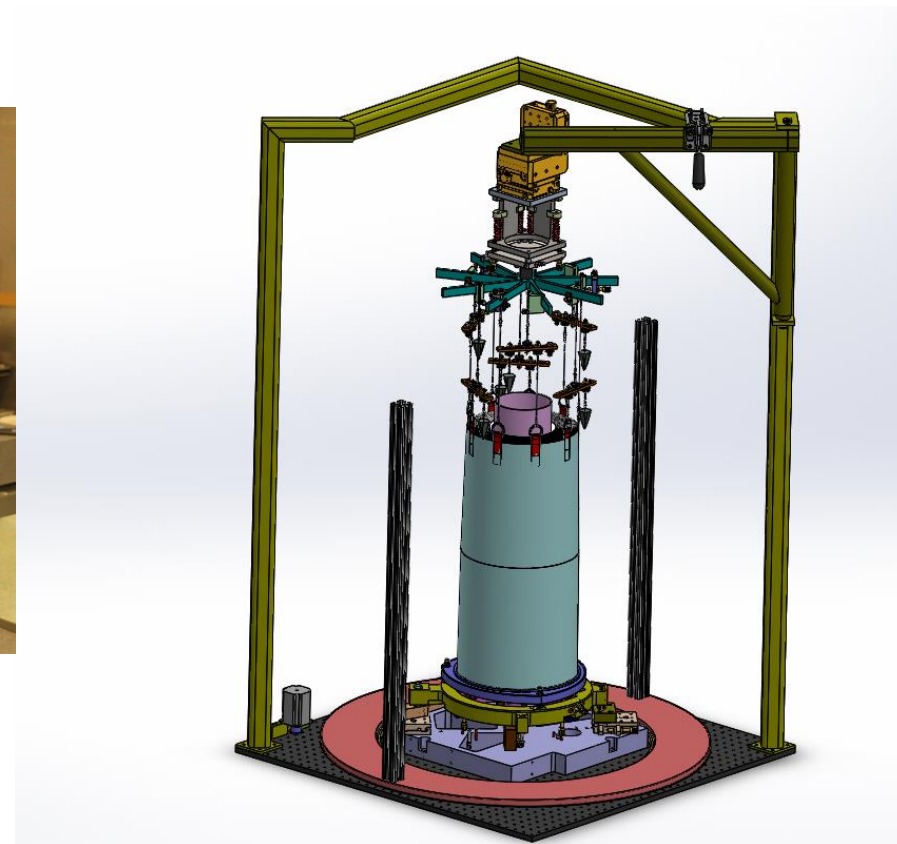
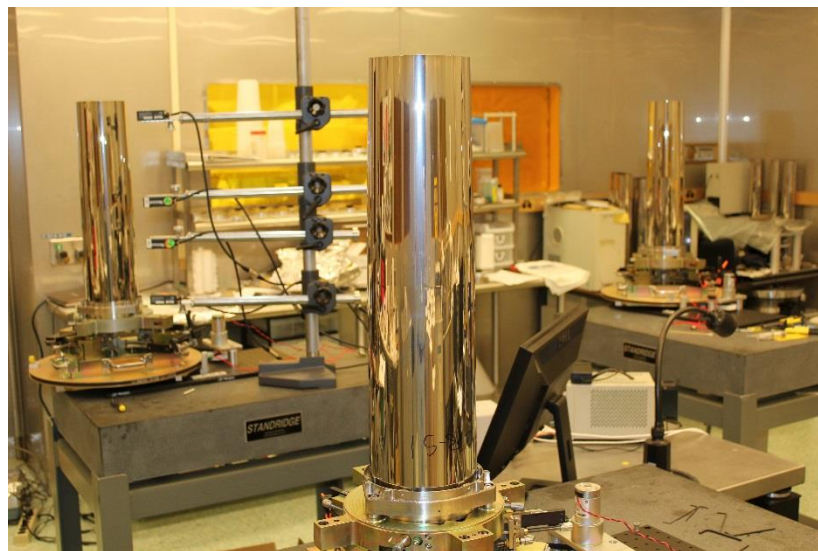


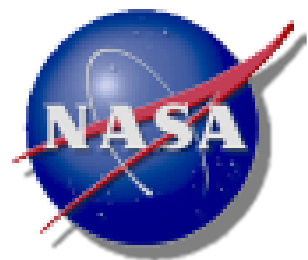
Alignment

Strings approach – XMM

Equalizing the strings tension

Redistribute the
displacements from radial to
azimuthal direction





Conclusions

- Pros:
 - Alignment of H and P sections is not need
 - Full Shells are self-supporting
- Cons:
 - Any displacement results in global shape change
- There is a “sweet spot” for support points during the alignment
- The support approach aims to minimize the radial displacements